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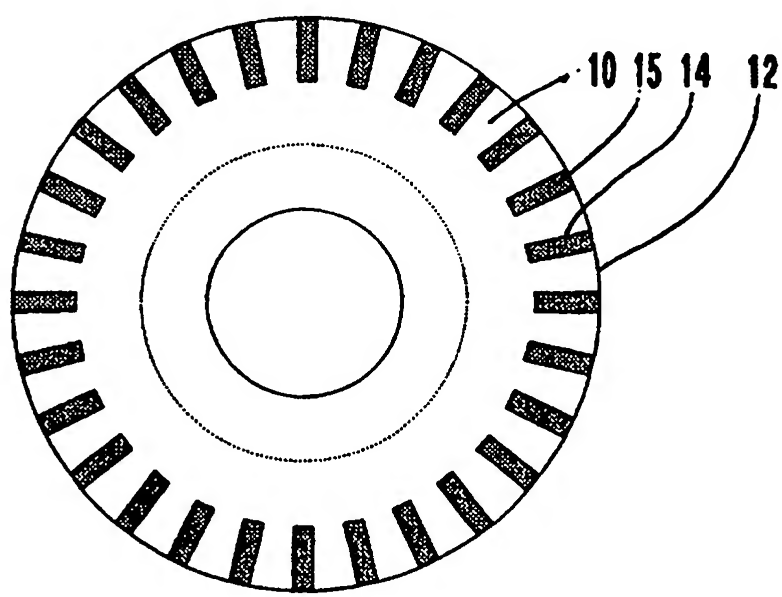
(57) Abstract

The invention relates to an electric motor comprising stator means (20) and a solid rotor means (10) disposed within the stator means. A squirrel cage means (16) is disposed within groove means (14) provided in connection with the periphery (12) of the rotor means. The squirrel cage means (16) comprises a plurality of essentially axially extending rotor bar means (15) which are essentially narrow relative to the height thereof.



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An electric motor and a method in an electric motor and use thereof

The present invention relates to an induction motor structure in accordance with the preamble of claim 1, and more precisely, to a motor comprising a solid rotor means.

The present invention relates further to a method in accordance with the preamble of claim 10 for improving an induction motor provided with a solid rotor means.

In addition, the present invention relates to a preferred use of the motor means and the method according to the present invention.

The electric motors operating in accordance with the principles of an induction machine have usually been machines using so called laminated rotors. A related problem of these are the vibrations which occur already at relatively low rotational speeds and are due to the structure of the rotor, especially due to the poor bending stiffness and partly also due to the poor torsional stiffness thereof. The so called critical frequency of the laminated rotor is met at relatively low rotational speeds, which are way too low, especially in view of rotational speeds which are raised from the normal. The manufacture of the laminated rotor requires also several working stages and special tools and machines, the manufacture thereof being thus slow and expensive to accomplish.

Therefore, it is prior known to use in the electric motors using high rotational speeds so called solid rotors manufactured eg. by a lathe from a uniform billet, by means of which an essentially more rigid and stiff structure is achieved. However, in this solution the rotor resistance is essentially increased and the power ratio of the machine decreased, being typically about 0.6 - 0.7. The coefficient of efficiency for this kind of rotor is also poor. The solid rotors, which are manufactured from one piece and in most cases are smooth from the outer periphery thereof, are, however, commonly used in short circuit motors using a rotational speed which is essentially higher than in normal motors, such as up to 200 000 1/min. However, the problem of these is also the above mentioned poor coefficient of efficiency and overheating, even in

such cases where smaller rotational speeds, ie. so called ordinary speeds, are desired, such as speeds less than 20 000 1/min.

One example of an improved solid rotor application is disclosed by GB patent No. 1 427 818. A rotor means thereof comprises a cylindrical rotor shaft of low carbon iron which is provided with so called copper squirrel cage for decreasing the rotor resistance. The axially extending portions of the disclosed squirrel cage, ie. the rotor bars, are formed so as to have a semispherical shape so that the widest portion thereof is disposed in the plane of the circumferential rotor surface while the arcuate semispherical surface is disposed within the similarly shaped groove in the rotor.

Although the solution provides advantages in the rigidness of the rotor and decreases the resistance, the poor efficiency is, however, still a problem. The losses lead, in addition to the poor efficiency, to a remarkable overheating during the use. Different cooling systems are provided so as to solve the overheating problem, but the power required by them has further decreased the efficiency coefficient. In addition, the disclosed solution uses an essentially small air gap (lines 81-82 in page 1), which causes remarkable additional losses. A remarkable problem in view of the manufacture has been the difficulty in attaching the essentially wide semispherical copper portions of the squirrel cage and the fastness thereof in the rotor, especially in higher rotational speeds. In addition, the citation does not disclose or suggest any manner to utilize the disclosed rotor means in other types of motors than in the high speed motors. The disclosed solution has not, eg. due to the above reasons, gained any common success in the field of the electric motors.

The object of the present invention is to overcome the disadvantages of the prior art and to provide a totally new type of structure for an electric motor comprising formed stator means and a solid rotor means provided with a squirrel cage means which is implemented by a new manner. By means of the inventive solution an induction motor structure is provided, having essentially improved efficiency and other properties thereof when compared to the known solutions and in which solution there are no significant overheating problems, as is the case with the prior art motors.

It is also an object of the present invention to provide a structure and a

method for providing a motor means which can be used within a wide range of rotational speeds.

An object of the present invention is to provide a solid rotor motor structure having an essentially low field weakening point. This enables eg. loading of the machine by a constant power in an essentially wide range of rotational speeds.

An object of the invention is also to provide a rotor means of a motor which is easy to manufacture, whereby a method utilizing the rotor means is thus easy and economical to implement.

An additional object of the invention is to provide a rotor means having an essentially low rotor resistance.

An additional object of the invention is to provide a motor structure, in which the speed of rotation does not drop essentially in response to a rapid increase in load.

An additional object of the invention is to provide a rotor means which essentially prevents the formation of tangential currents.

An additional object of the invention is a motor structure having an essentially sinusoidal flux distribution.

An object of the invention is also to provide a motor structure comprising a solid rotor in which an essentially small air gap can be used without any disadvantageous effects, whereby it is possible to increase the efficiency.

An object of the invention is to provide a motor structure having a size and weight which are smaller than those of the known induction motor solutions providing an equivalent power.

A still additional object of the invention is to provide a solution, in which the object to be rotated, such as a blower, a tool, eg. a machine tool, a pump etc., can be adapted directly to the rotor shaft or an extension thereof.

A still additional object of the invention is to provide a motor solution which

can be used as a spindle motor of a robot or similar machining apparatus performing movements in three axis space.

The invention is based on that surprising observation that characteristics which are improved from the prior known solid rotor motors can be achieved by a provision of a solid rotor means and therewith cooperating stators means, in which combination such rotor means are used which are provided with grooves having an essentially narrow and deep shape and a cage means adapted therein, a motor structure is provided in which the effect of the air gap permeance harmonics is decreased essentially compared to the known solutions, which is especially desirable when solid rotors are concerned.

More precisely, the arrangement according to the present invention is mainly characterized by what is disclosed in appended claims 1...9 and especially by the characterizing portion of claim 1. The method according to the present invention is mainly characterized by what is disclosed in appended claims 10...12 and especially by the characterizing portion of claim 10. A preferred use of the present invention the is mainly characterized by what is disclosed in appended claims 13 and 14 and especially by the characterizing portion of claim 13.

According to a preferred embodiment of the present invention the apparatus comprises an essentially rigid, from one piece manufactured solid rotor means, the circumferential surface thereof being suitably provided with squirrel cage means, which preferably are of copper or similar material having good electrical conductivity, such as aluminium, brass etc. material per se known. The axially extending portion of said squirrel cage means, ie. so called rotor bar, is shaped so as to be essentially deep in relation to the width thereof, by means of which the effect of the air gap permeance harmonics to the stator means is essentially decreased. This enables a usage of a smaller air gap than in the prior art with no disadvantageous effects.

According to one preferred embodiment an end or a short circuit ring of the squirrel cage means is essentially deep (high), by means of which an advantage is obtained in the form of further decrease in the rotor resistance.

The stator means are preferably formed from a plurality of adjacent stator plates and a suitable isolation therebetween. The stator slots in the central

bore receiving the rotor means are suitably shaped such that they preferably form a stator tooth at each side of the slot, said tooth extending towards the rotor means.

According to one preferred embodiment the rotor means is manufactured such that the circumferential shape thereof is machined by a lathe from a suitable steel billet, and subsequently a desired amount of essentially axially extending, essentially narrow and deep grooves are provided eg. by means of a milling tool or a laser machining. The squirrel cage means disposed into the grooves is preferably attached to the base material by electron beam welding (EB welding) or laser welding.

According to one preferred embodiment the material disposed within the groove is attached, eg. is welded, to the base material only from the other side thereof. According to a still further embodiment a suitable air gap is maintained between said unattached side and the rotor material. According to one form, preferred especially in view of the manufacture, so called bimetal sheet, such as FeCu sheet, is disposed within the groove, which is welded or otherwise attached to the rotor means only from the steel portion side thereof.

According to the present invention, the characteristics of an induction electric motor are improved by a method wherein the resistivity of a solid rotor means disposed rotatable within stator means is increased by means of a squirrel cage means provided in the rotor means. The effects of permeance harmonics of the rotor means are decreased by providing the number and shape of the essentially axially extending rotor bar portions of the squirrel cage means arranged to the rotor means such that the air gap flux distribution reminds the shape of an essentially sinusoidal shaped stepped curve with fine steps. The air gap flux is preferably further controlled by an appropriate formed tooth-like stator slot shape provided in the slot means of the stator means.

Due to the wide constant power range it is preferred to utilize the invention eg. in machine tools for rotating of rotatable tools. According to one more precise embodiment the motor structure according to the present invention is utilized as a spindle motor of a machining apparatus movable in three axis space, such as a robot.

Significant advantages are obtained by means of the present invention. The efficiency of a solid rotor motor is essentially improved when compared to the known solutions, while the problem relating to the motor overheating is significantly decreased. By means of the invention the size and weight of the motor are decreased, when compared to known motors having an equal performance. The motor according to the invention gives an essentially even maximum power in an essentially wide rotational speed range, such as within a range of 6 000 - 30 000 1/min or 1 000 - 5 000, in other words in minimum/maximum speed ratio range about 1/5 or eg. 1/8. In addition, the drop in the rotational speed of the inventive motor structure is essentially small in case the load rapidly increases, which leads into, among other things, a decreased need for detecting and controlling the rotational speed than in the known solutions. In addition, the motor does not present an essentially high slip. Due to the good characteristics, such as the small size and weight and the wide rotational speed range and the even power curve, the motor and method of the present invention is applicable in various instances, as the same motor can be applied to several different uses. The manufacture of the motor means of the invention is easier to accomplish than those of the prior art, but still a more durable and reliable structure, eg. in view of the fastness of the rotor bars, is provided.

In the following the present invention and the other objects and advantages thereof will be described by way of examples with reference to the annexed drawings, in which similar reference characters throughout the various figures refer to similar features. It should be understood that the following exemplifying description of the invention is not meant to restrict the invention to the specific forms presented in this connection but rather the present invention is meant to cover all modifications, similarities and alternatives which are included in the spirit and scope of the present invention, as defined by the appended claims. It is further noted that by the term stator means all such stator designs are meant, which can be provided with shaped stator slots in accordance with one form of the invention. In addition, the term rotor bar is intented to mean the portion of the squirrel cage means extending in an essentially axial direction between the short circuit ring means.

Figures 1a and 1b are simplified schematic views from side and in section of a rotor means of the motor structure according to the present invention.

Figure 2 discloses a stator plate means of the invention.

Figures 3a, 3b and 3c are schematical presentations relating to the stator means of a motor construction according to prior art and of the present invention.

Figures 4a, 4b and 4c disclose schematic views of additional embodiments of the present invention.

Figures 5a and 5b disclose one testing arrangement used for the invention, and figures 5c and 5d are tables illustrating the test results.

Figure 6 discloses a further embodiment of the rotor means.

Figure 7 discloses a schematic view of one preferred application of the invention.

Figure 1a discloses one solid rotor means 10, which is manufactured from a uniform steel billet, of the induction electric motor structure according to the present invention. The sectioned view thereof along line A - A is disclosed in figure 1b. As can be seen from the figures, the periphery 12 of the rotor means 10 is provided with a grooving, into which a squirrel cage means 16, which is preferably of copper material, is disposed. The shape of the grooves 14 receiving the essentially axially extending portions of the squirrel cage means 16, ie. the rotor bars 15, is arranged so as to be essentially deep in relation to the width thereof. Especially preferred values for the rotor bar width/depth ratio are the ones in the range of 1/3 - 1/10. It is to be noted that even though the bars of the figures are always having an essentially rectangular sectional shape, they may also, if necessary, differ from that, being for instance wedge-like, triangle-like or barrel-like or concave from some surfaces thereof without departing from the general idea of the invention.

According to the invention, essentially narrow rotor bars 15 are disposed in an essentially tense configuration on the periphery 12 of the rotor. The examples disclosed by figures 1a and 1b have 28 grooves, the depth of one groove 14 being about 10 mm and the width thereof being about 3 mm. The length of the test rotor manufactured from Fe 52 constructional steel was about 160 mm and the diameter thereof was about 87.5 mm.

Figure 1b discloses also short circuit rings 13 of copper and disposed at the ends of the squirrel cage means 16, which were about 30 mm deep (high).

The copper squirrel cage means 16 used in the test rotor 10 of figures 1a and 1b was attached to the rotor by electronic beam welding. Alternatively, eg. an aluminium squirrel cage means could have been used, by means of which it is possible eg. to decrease the effects of the centrifugal forces affecting to the rotor due to the lighter nominal weight of aluminium. The rotor bars 15 provide a good axial electrical conductivity, and thus, from this point of view, the motor construction gives a high torque with a minimum slip. Thus the motor losses are further decreased, especially with high power levels.

In addition, the essentially axially extending bars 15 of the rotor according to figure 1b are slightly twisted to have a spiral form, that is at an angle with the axial direction, so that the other end of each of the coil bars 15 is moved sideways about an amount which equals to one groove pitch. This is, however, only an additional embodiment, and is not by any manner necessary for implementing the invention.

The rotor means 10 provided with a preferred groove shape, as is disclosed by figure 1b, does not cause any essential heating of the stator means, as the effect of the permeance harmonics of the squirrel cage 16 provided into the essentially narrow rotor grooves towards the slots 21 of the stator means 20, or eg. to teeth 22 of the embodiment of figure 2, is essentially small compared to the prior art using essentially wide rotor bars or rods. This is caused by, among other things, the fact that the essentially strong permeance harmonics existing in the prior art solutions would cause iron losses in the stator teeth 22 formed in a manner as is disclosed by figure 2. However, it is possible to minimize these losses by the rotor structure of the present invention.

An advantage is also obtained in the air gap flux distribution by means of the essentially narrow rotor grooves. The ideal distribution would be completely sinusoidal, but it has not been possible to obtain this by the known squirrel cage solutions. When using many essentially tensely disposed and in the tangential direction essentially narrow grooves a situation is, however, obtained in which the flux distribution having a shape of a stepped curve has a

great number of substantially fine steps, whereby the shape of the stepped curve can be brought extremely close to the sinusoidal form, which is considered as ideal.

Figure 2 discloses a preferred form of the stator plate 20, showing the stator slot means 21 and the formed portions 22. Even though it is not illustrated, it is to be noted that the skilled person understands that the inventive motor construction consists of a combination in which the rotor means 10 of figures 1a and b is disposed in the bore 24 of the stator plate means 20, disclosed eg. by figure 2. In addition, it is apparent that it is possible, if deemed necessary, to provide the motor construction with suitable cooling means, such as channel and conduit equipment required in air or liquid cooling.

Figure 3a is an enlarged view of a portion of the shape of a slot according to the prior art, and figure 3b is a similar enlarged partial view of one tooth means 22 formed in accordance with the present invention. It is noted herein that figures 3a and b are not in a precise scale relative to each other. The diagram of figure 3c illustrates the difference between the prior art and the invention in the flux density provided by the stator slots in an ideal idle state, wherein curve a) corresponds to the prior art, ie. the figure 3a arrangement, and curve b) corresponds to the structure of figure 3b.

As explained, figure 3a discloses one form of the stator slot 21' utilized in the prior art. The flux density distribution provided by it within the electrical air gap l_s is illustrated by lines 26'.

The stator slot form 21 of the invention is disclosed by figure 3b. Both sides of the stator slot are provided with a tooth 22 extending from the stator plate 20 to the rotor bore 24. The influence thereof to the flux density distribution can be easily seen by means of the lines 26 illustrating the flux. In the situation of figure 3b it is also possible to divide the air gap to an electrical air gap l_s between the rotor and the stator and to a shorter physical air gap l_f between the rotor and the top of the tooth, as is illustrated by the figure. The tooth 22 assists especially in that there in no need to increase the electrical air gap l_s to be greater to provide a more even flux on the peripheral surface 12 of the rotor 10. A similar effect is also provided with tooth shapes which differ from that of figure 3b, and this connection the essential matter is that the edges of

the stator slot are provided with suitably formed tooth means for providing an even flux on the rotor surface such that there is no need to increase too much the electrical air gap.

From the diagram of figure 3c it can be noted that by means of the stator slot means (tooth) 22 having a tooth-like shape a flux distribution (b) is provided which is essentially more even than what the prior art solution (a) provides. The stator means 20 provided with slots formed in accordance with the disclosure of figure 3b, and more precisely, the permeance harmonics thereof, do not essentially heat the rotor 10, in other words, the effects of the permeance harmonics are minimized.

A preferred additional embodiment of the rotor means is disclosed in the schematic cross sectional view of figure 4a, according to which the axially extending rotor bar 15 of the squirrel cage means disposed within the groove is attached from only one side 32 thereof to the groove 14. The attachment can preferably be accomplished by eg. electronic beam welding (EB welding) or laser welding. By means of this solution it is possible to obtain advantages eg. in view of the required amount of welding.

In addition, even though it is not always necessary, it may be advantageous to leave even a small air gap 35 between the groove 14 and the portion 15, as is disclosed by figure 4a. The air gap may preferably be about 0.1 - 2 mm.

According to one alternative disclosed by figures 4b and c a suitable so called bimetal sheet is disposed within the groove 14, which may preferably be a iron-copper sheet (FeCu), such as disclosed by figure 4b. Such a bimetal sheet, in which the different materials, such as copper and steel 15' and 15'', can be attached together eg. by means of explosive welding, is known by the skilled person and commercially available. The rotor means according to figure 4b is especially easy to manufacture, as it is possible to weld or otherwise attach this kind of sheet from the location designated by an arrow only from the steel portion side thereof to the rotor made of steel. In other words, this enables an attachment of two smooth joint surfaces of essentially similar material to each other by simple and cheap attachment methods. Further saving is obtained, for instance, due to the fact that the requirements for the preparations, such as in view of the smoothness and the level of oxidization of

the joint surfaces, are not that strict as what is the case, for instance, in view of copper to iron joints.

Figure 4c discloses in a reduced scale the situation of figure 4b, shown as from the side thereof. The end ring 18 is also manufactured correspondingly from the FeCu sheet. In this case it is possible to use preferred welding of the steel portions of the end plate 18 to the rotor material from the locations indicated by an arrow, and the copper portions may be brazed or welded to the copper of the rotor bars.

In addition to the advantages in the field of manufacture, such as the improved easiness of attachment, decreased need for welding and more fast manufacture, it is possible to further prevent the formation of tangential currents by means of the rotor bar means 15 attached only from the other side thereof, whereby the characteristics of the solid rotor 10 correspond essentially the same of the laminated rotor and it is possible to partially separate the magnetic circuit and the electric circuit from each other. When a common target in general is, for instance, that the current travels axially in the rotor 10, ie. in the direction of the rotor bar 15, improves this kind of rotor arrangement further the motor characteristics obtainable by this invention, especially the efficiency coefficient of the motor.

The figure 5a and the table of figure 5b disclose one test arrangement in which a 12 kW, 300 Hz solid rotor motor according to the present invention was tested. In part of the tests the apparatus disclosed by figure 5a and designated by a dashed line was replaced by so called static converter or inverter 40. This kind of inverting means are per se known, and commercially available.

The line diagrams of figure 5c and 5d show the test results of a comparison, in which three different solid rotor structures (see 5a and 5b) were compared with different power supplies. The used rotor structures were (curve numerals): smooth rotor (1 and 4), grooved rotor (2 and 5) and a rotor provided with a squirrel cage in accordance with the present invention (3 and 6). The rotors were otherwise similar, but the distinction relied on the provision of the grooving (2 and 4) and the squirrel cage according the invention (3 and 6).

Figure 5c discloses a comparison of the torque characteristics of the motor in the described test motor, which was provided with 300 Hz inverter supply

(1-3) and sinusoidal supply (4-6), while the rotational speed varied within a range of about 280 - 300 1/s. As can be noted from the graph, the grooved rotor (2, 5) gives an improved torque curve with an equal slip than what is obtainable by the smooth rotor (1,3). However, the clearly best results were obtained by the inventive motor provided with the copper squirrel cage means (3,6). The nominal slips in the sinusoidal supply were: for the smooth rotor 3.5 %, for the grooved one 2.2 % and for the one provide with the squirrel cage 0.3 %.

The curves of figure 5d illustrate the obtained efficiency relative to the output power, when the voltage was 400 V and the frequency was 300 Hz. As can be noted, the efficiencies of the different motors are almost the same up to the power of 5 kW. After this point even the smallest losses in the motors are becoming essential, and it can be seen that the efficiency of the motor provided with the inventive squirrel cage rotor is clearly the best, and that it also gives the widest substantially even power in both supply methods, and also the greatest power.

Figure 6 discloses one further embodiment. In this the inventive rotor bar means 15 provided in the rotor means 10 are in an inclined position, ie. at an angle towards the radial direction. In addition, the grooves 14 are preferably closed by welding from the peripheral surface 13. The disclosed rotor structure does not cause any permeance harmonics at all. It is possible to fit in the rotor an essentially great amount of copper or similar material, the fastness whereof within the groove 14 is especially good due to, for instance, the inclination, but also because of the closure of the groove from the top. This kind of structure is preferred in big motors rotating in one direction only, but the application possibilities thereof are, however, not limited to these, and it can be well used in the smaller and/or two directional motors.

According to one preferred embodiment disclosed by figure 7 the motor structure 1 comprising the inventive rotor means 10 and an appropriate stator means 20 is mounted to form a drive apparatus, such as spindle motor 1, of a robot means 40 or similar means adapted to move in a three dimensional space. The arrangement is now preferably such that the motor 1 is adapted to drive or rotate the machining spindle 42 arranged in the robot 40 or similar, and thus the machining tool 43 or similar rotating tool attached therein.

The motor structure according to the present invention is especially suitable to be used in machining, as the general requirement for the machining apparatus motors is the even characteristics thereof, such as power and torque, through out the entire rotational speed and power range. Usually the rotational speeds used in connection with the rotating tools of the robots vary between 10000 - 20000 1/min, the approximate power requirement thereof being typically < 20 kW. Therefore the inventive motor structure having an essentially light nominal weight and size and a small slip is especially well suited to the robot applications or similar, in which there exists a need to move the motor for instance in a three axis space and in which the power requirement increases rapidly eg. in situations where the tool is rapidly placed into engagement with the surface of the object to be machined.

Thus the invention provides an apparatus and a method, by means of which an essential improvement is achieved to the characteristics of the solid rotor motors. These motors are especially well suited to be applied in applications requiring medium speed and high speed motors. The inventive structure is, however, small in size and light, simple from the structure thereof and easy to manufacture, and thus economical to implement, and also reliable in operation thereof.

It is to be noted that the foregoing examples of the embodiments of the invention are not limiting the scope of the invention defined by the claims. With the aid of the above description and the drawing it is apparent for the skilled person to use the inventive method and apparatus in many various applications, such as a motor for different fans, blowers, and pumps, or as different movable or fixed drive, the examples thereof being different drives for paper making machines and the electric motors for ships and trains, and so on.

Claims

1. An induction electric motor structure, comprising stator means (20), coaxially inside the stator means disposed cylindrical rotor means, said rotor means being an essentially rigid solid rotor means (10), wherein several essentially axially extending groove means (14) are provided in connection with the periphery (12) thereof, and a squirrel cage means (16) disposed within the groove means (14), the material thereof having a greater electrical conductivity than is the electrical conductivity of the material for the rotor means, c h a r a c t e r i z e d in that the several rotor bar means (15;15',15'') of said squirrel cage means (16) extending essentially axially and in close relation to said periphery (12) are essentially narrow relative to the height thereof.

2. A motor according to claim 1, c h a r a c t e r i z e d in that a plurality of formed stator slot means (21) are provided in the circumference of the stator means (20) center bore (24) receiving the rotor means (10).

3. A motor according to claim 2, c h a r a c t e r i z e d in that said stator means include a plurality of stator plates (20) disposed adjacent to and isolated from each other in the axial direction of the motor, the stator slots (21) thereof having projections (22) at both sides thereof extending towards the rotor means, said projections being adapted to guide air gap flux towards the rotor means such that an essentially sinusoidal flux distribution (26) becomes established over the entire periphery (12) of the rotor means (10).

4. A motor structure according to any of the preceding claims, c h a r a c t e r i z e d in that at least a part of the rotor bar means (15) of the squirrel cage means (16) is attached only from the other side (32) thereof to the side surface (31) of the receiving groove (14) of the rotor means (10), whereas the other side surface (34) of the rotor bar means (15) is unattached.

5. A motor structure according to any of the preceding claims, c h a r a c t e r i z e d in that the rotor bar means (15) to be disposed within the rotor means groove comprises at least two portions (15,15''), wherein one portion (15') thereof is of material having better electrical conductivity than is the same for the rotor means and one portion (15'') thereof is of essentially similar kind of material to that of the rotor means material.

6. A motor structure according to claim 4 or 5, characterized in that an air gap (35) is provided between said unattached side surface (34) of the rotor bar means (15) and the corresponding side surface (33) of the receiving groove of the rotor means (10).

7. A motor structure according to any of the preceding claims, characterized in that said rotor bar means (15) are disposed in an inclined position relative to the radial direction within correspondingly inclined grooves (14) of said rotor means (10).

8. A motor structure according to any of the preceding claims, characterized in that the rotor bar means (15) extend in an angle relative to the axial direction in the periphery (12) of the rotor means (10).

9. A motor structure according to any of the preceding claims, characterized in that the arrangement further comprises a static frequency converter or inverter means (40) arranged between the power source and the motor (1).

10. A method for improving an induction electric motor, wherein the resistivity of a solid rotor means rotatably disposed within stator means is decreased by means of a squirrel cage means provided in the rotor means, characterized in that the method further includes decreasing of the effects of permeance harmonics of the rotor means (10) by providing the shape of rotor bar means (15) of the squirrel cage means (16) arranged to the rotor means such that air gap flux distribution has a shape of an essentially sinusoidal stepped curve having fine steps.

11. A method according to claim 10, characterized in that it further includes a step of guiding further the air gap flux by providing a suitably formed tooth-like shape (22) to the slot means (21) of the stator means (20) such that the flux distribution (26) is essentially sinusoidal over the entire periphery (12) of the rotor means.

12. A method according to claim 10 or 11, characterized in that it further comprises separation of the electric circuit and the magnetic circuit essentially from each other by providing a discontinuity between at least one

side (34) of said axially portions (16) and one side (33) of the groove (14) of the rotor means (10).

13. A use of an apparatus according to any of claims 1 - 9 or a method according any of claims 10 - 12, c h a r a c t e r i z e d in that it is applied in machining apparatus drives (40) for rotating rotating tools (42).

14. A use according to claim 13, c h a r a c t e r i z e d in that it is applied to a spindle motor of a robot (40) or similar machining apparatus arranged to be movable in a three axis space.

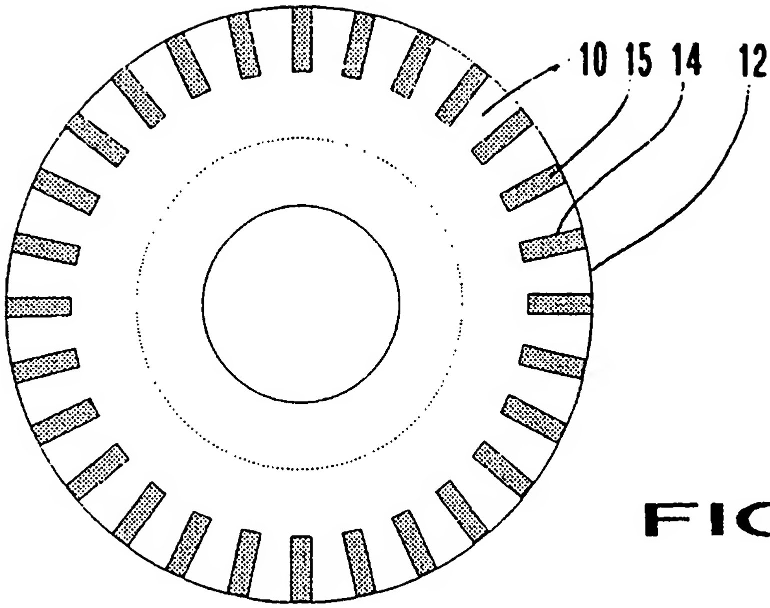


FIG 1b

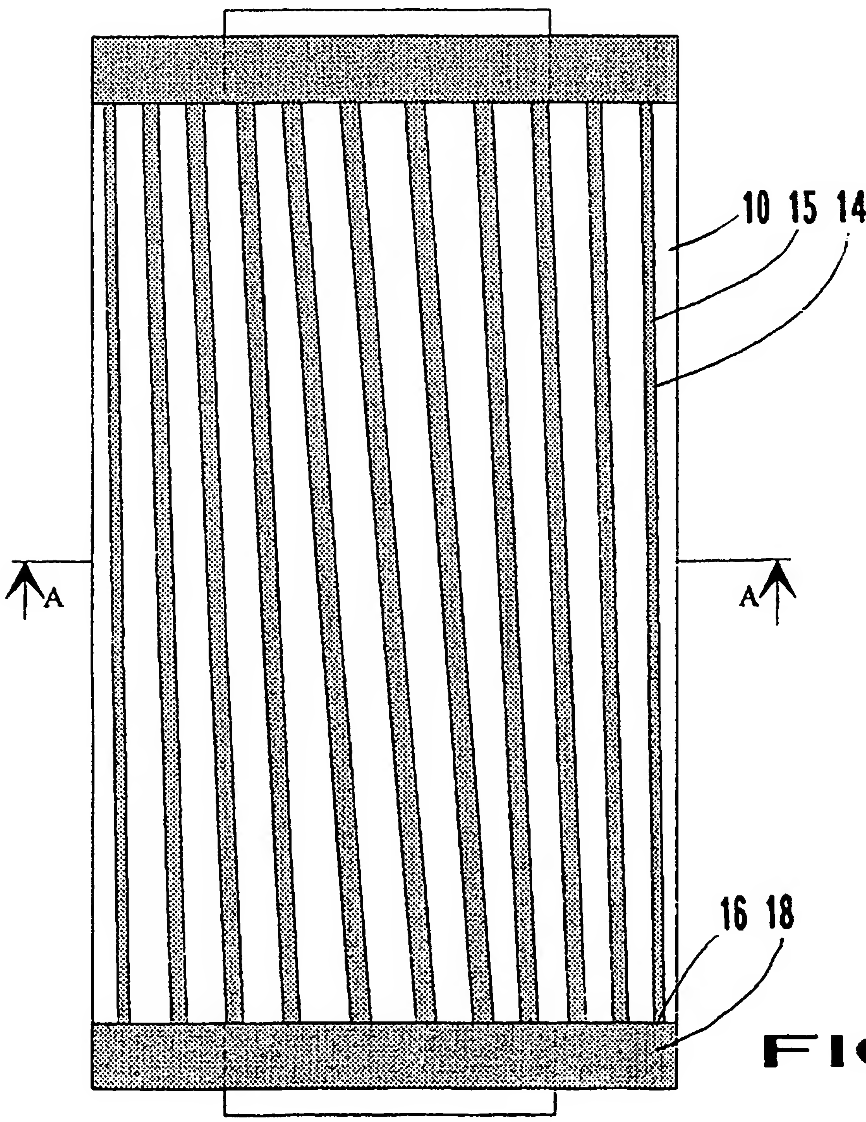


FIG 1a

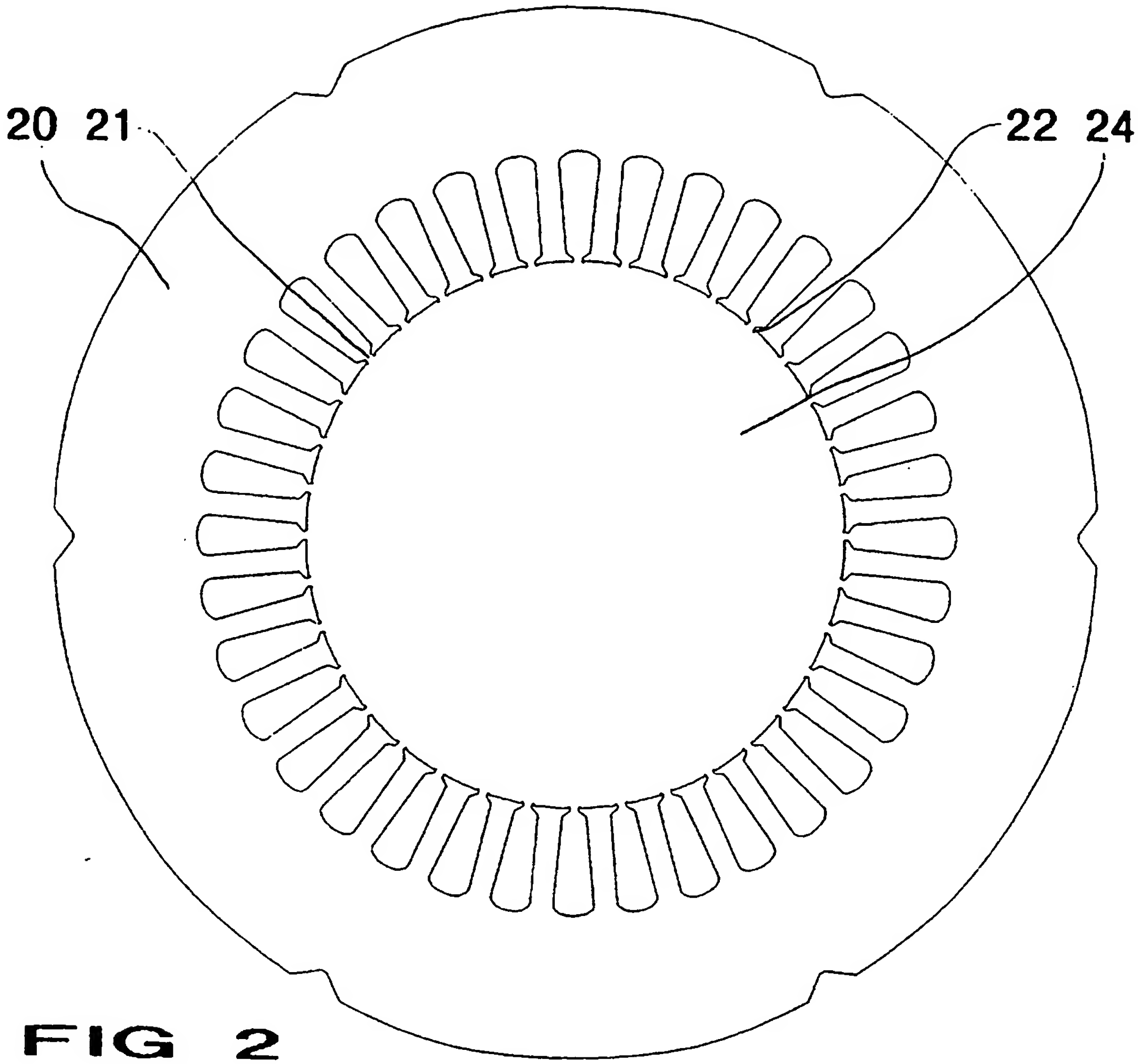
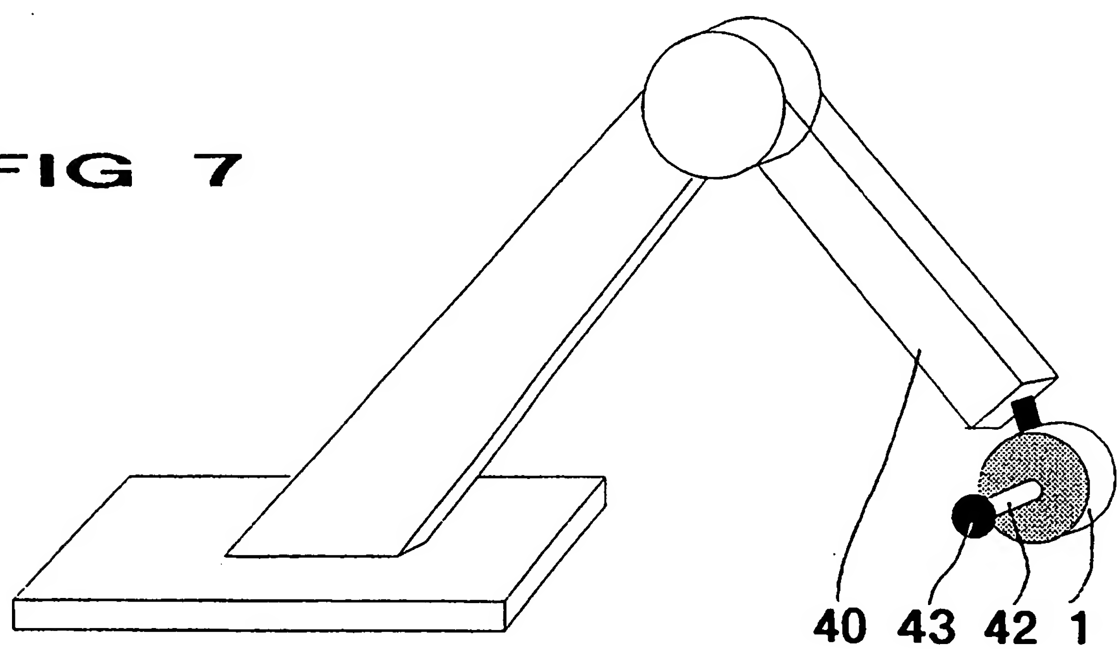


FIG 2

FIG 7



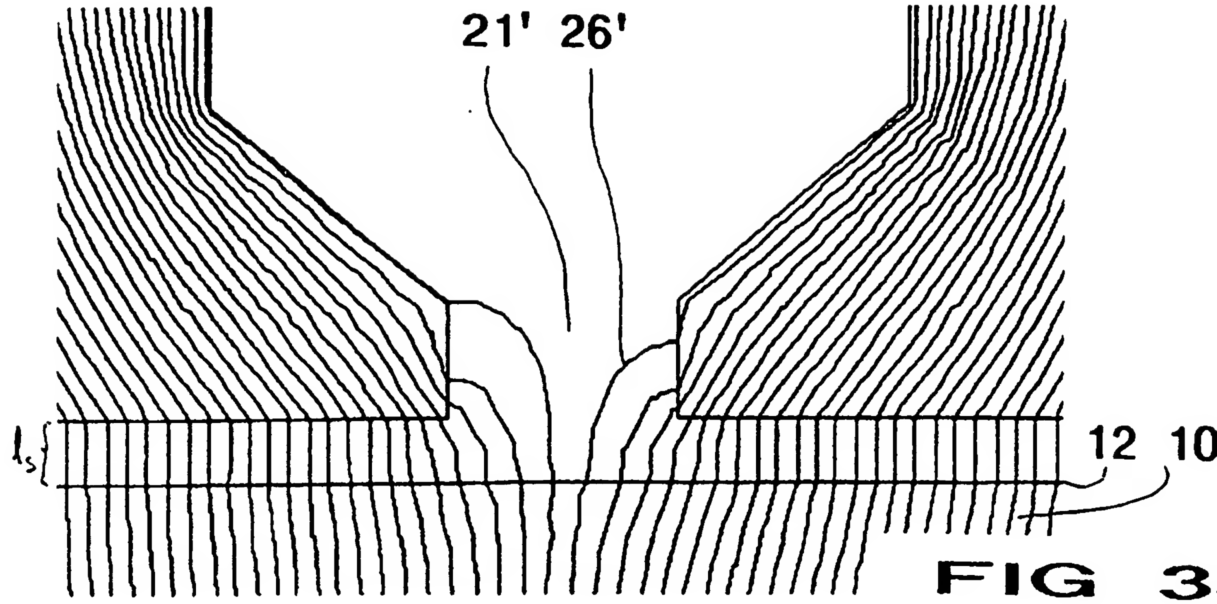


FIG 3a

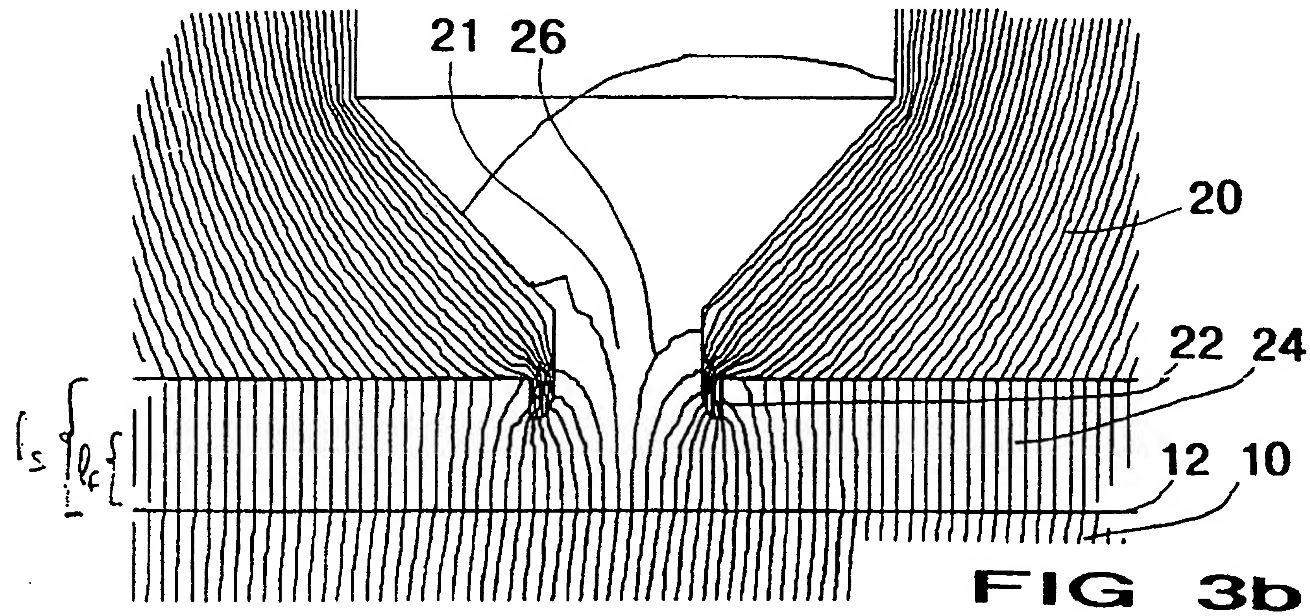


FIG 3b

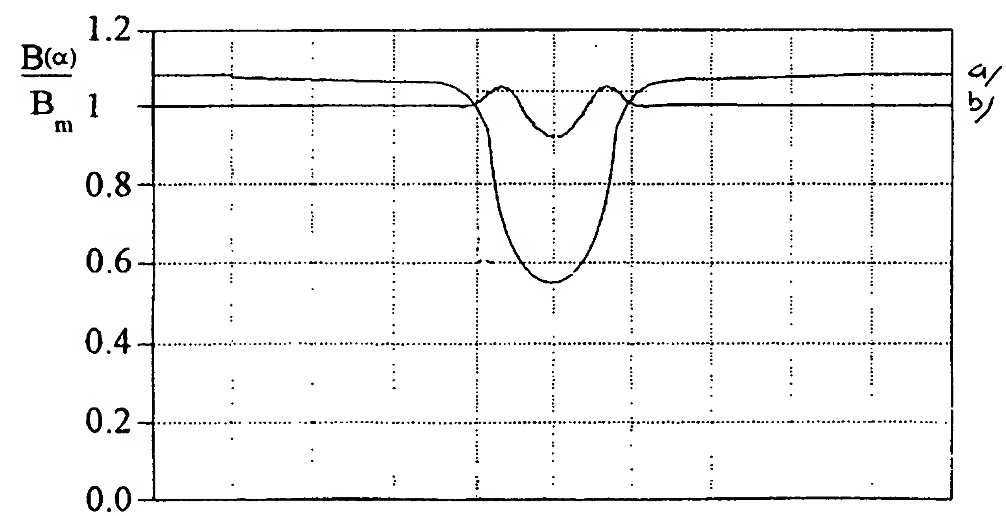


FIG 3c

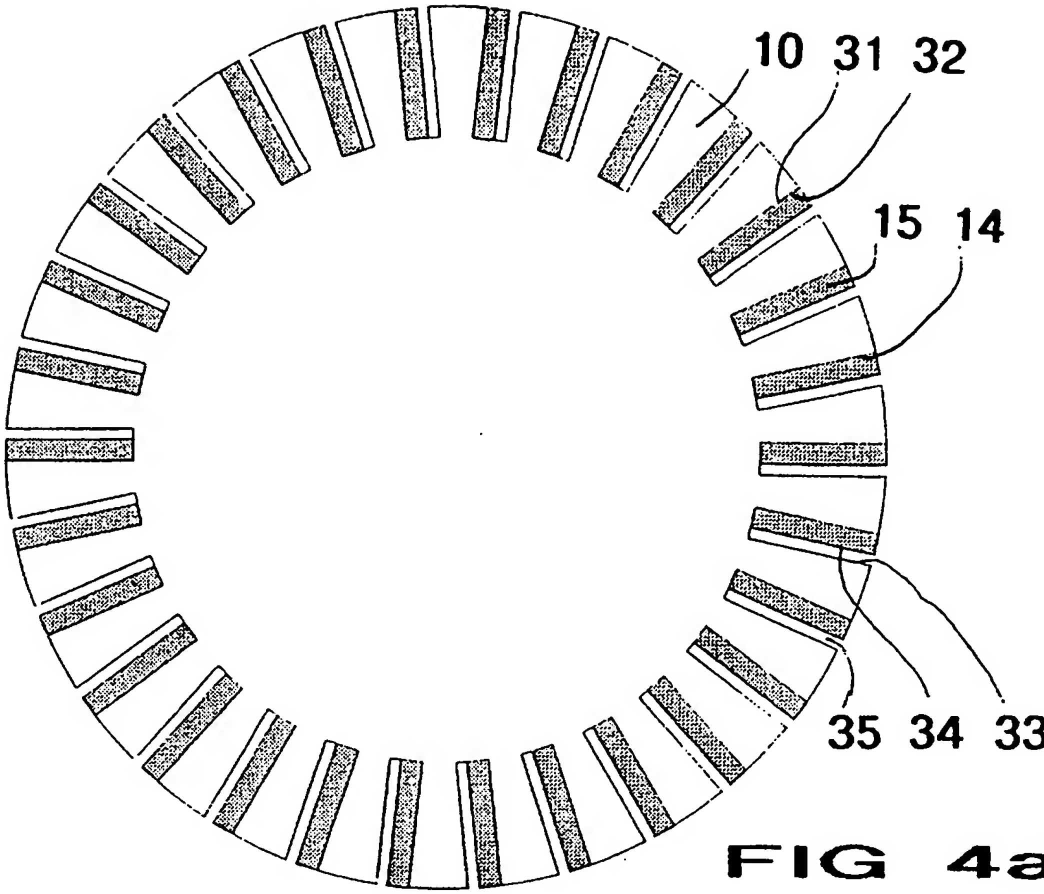


FIG 4a

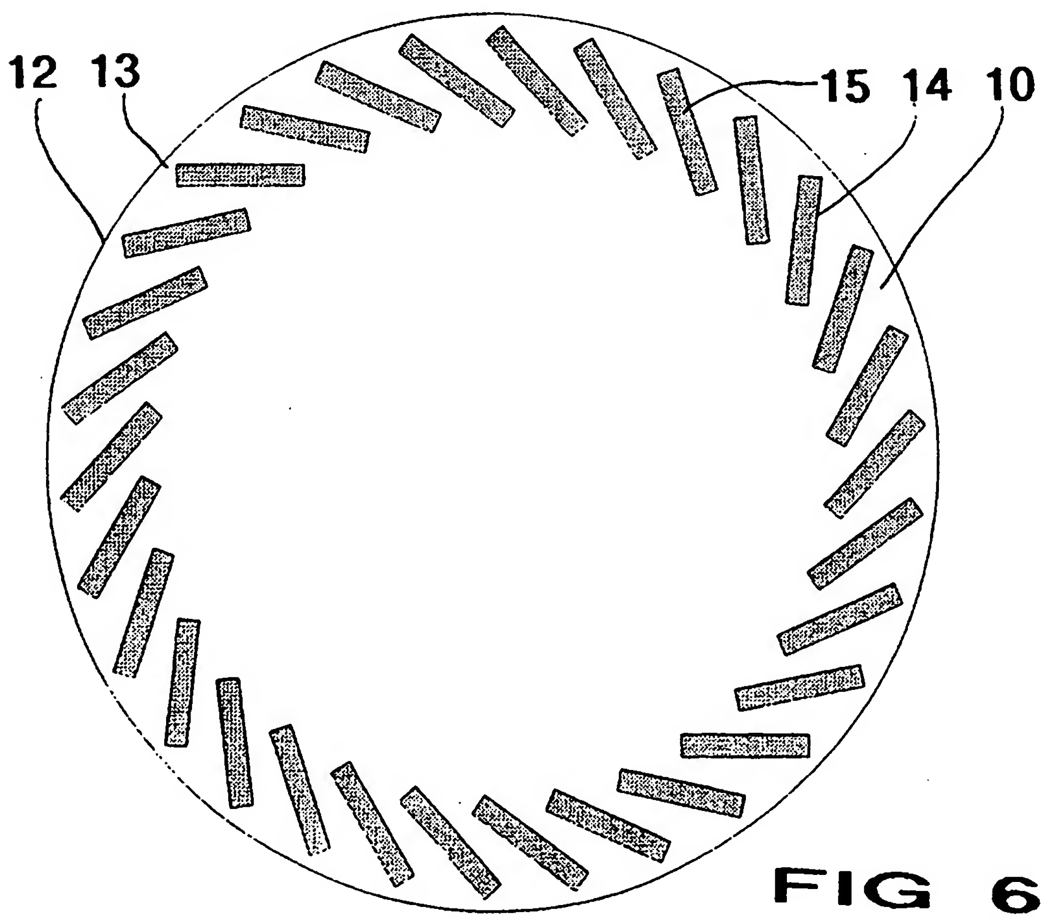


FIG 6

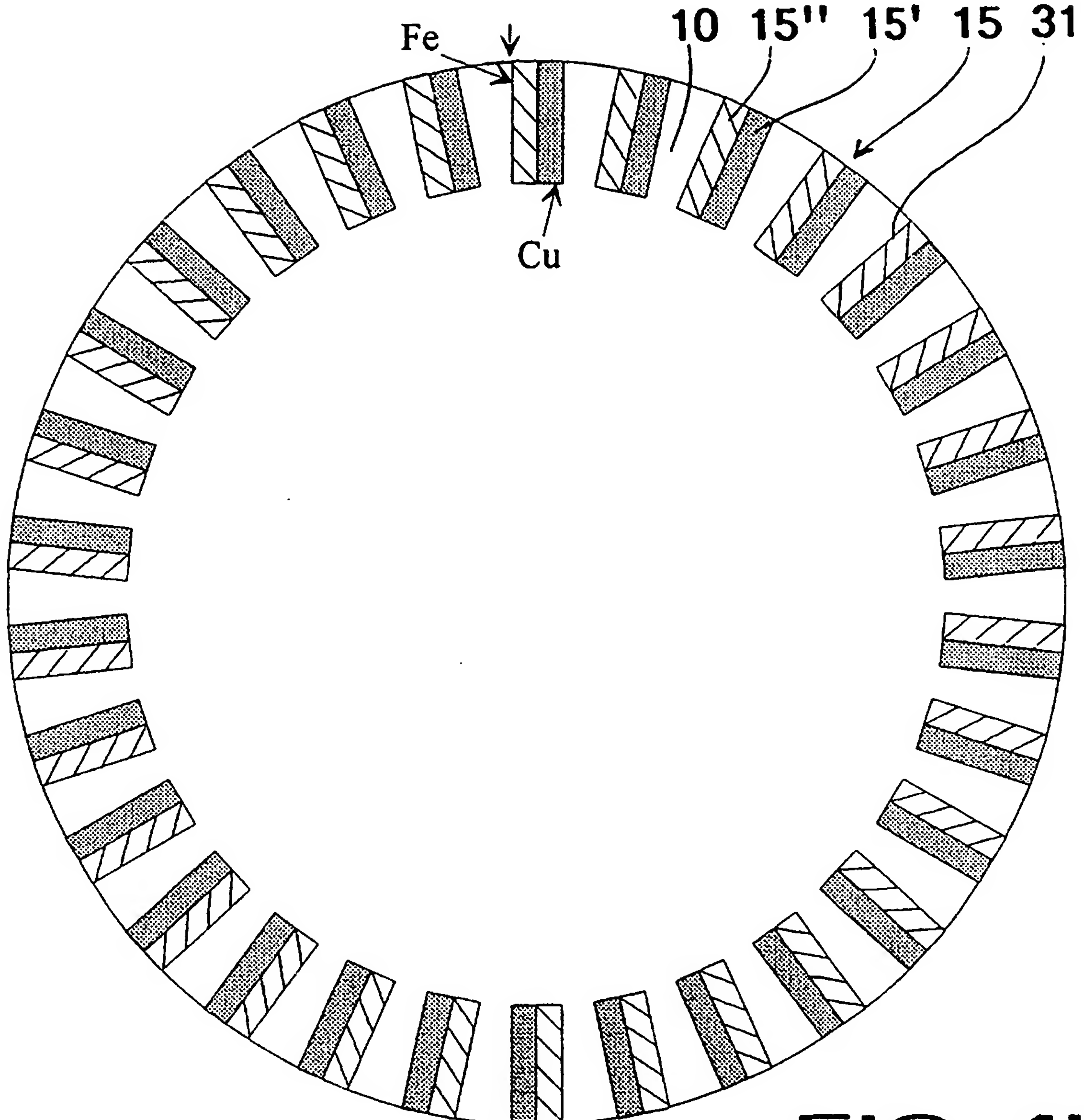


FIG 4b

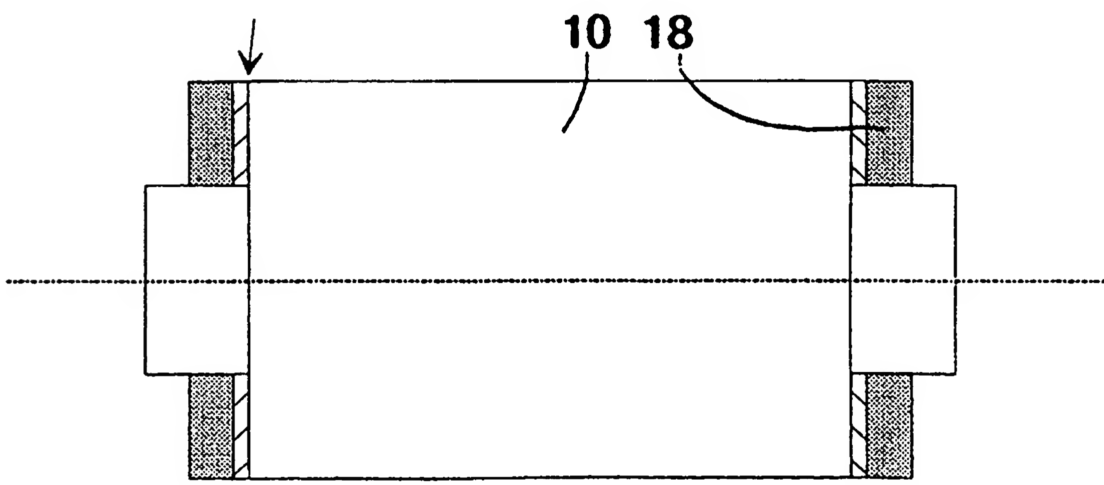


FIG 4c

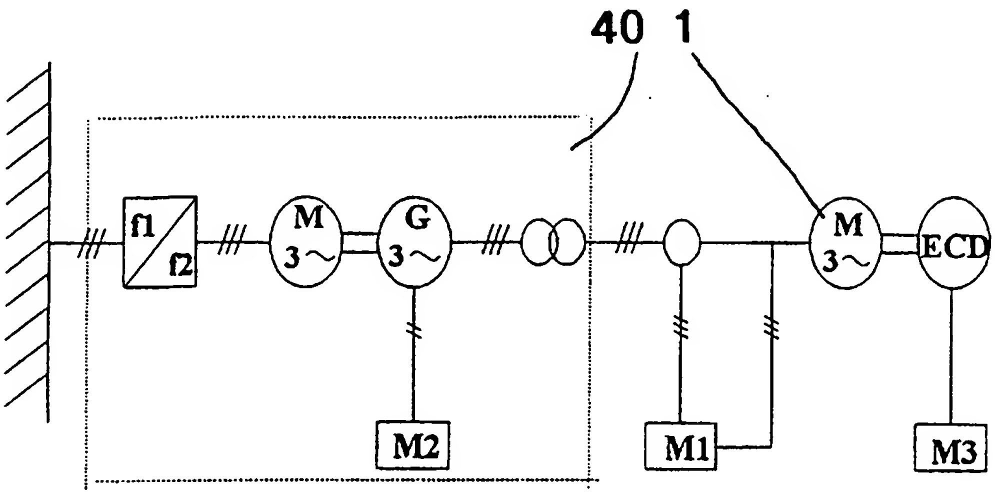


FIG 5a

TAB. 1. Parameters of the exemplifying machine provided with a solid rotor

Number of pole pairs, p	1
Number of phases, m	3
Number of stator slots, Q_s	36
Number of winding layers	2
Relative coil widtn w/τ_p	5/6
Winding factor ξ_1	0.924
Stator outer diameter / mm	170
Stator bore , D_s / mm	89,5
Width of the stator slot opening / mm	2.2
Stator stack length / mm	140
Air-gap, δ / mm:	0.95
Rotor length, l/mm	135
Rated Voltage U_s/V	400
Connection	delta
Rated current I_s/A	10/17.3
Rated frequency f/Hz	300
Stator phase resistance R_s/mΩ at 20 °C, 300 Hz	143
Stator leakage inductance, $L_{s\sigma}$/μH	420
Stator material: Bochum Hochfrequenzblech, 0.2 mm	

FIG 5b

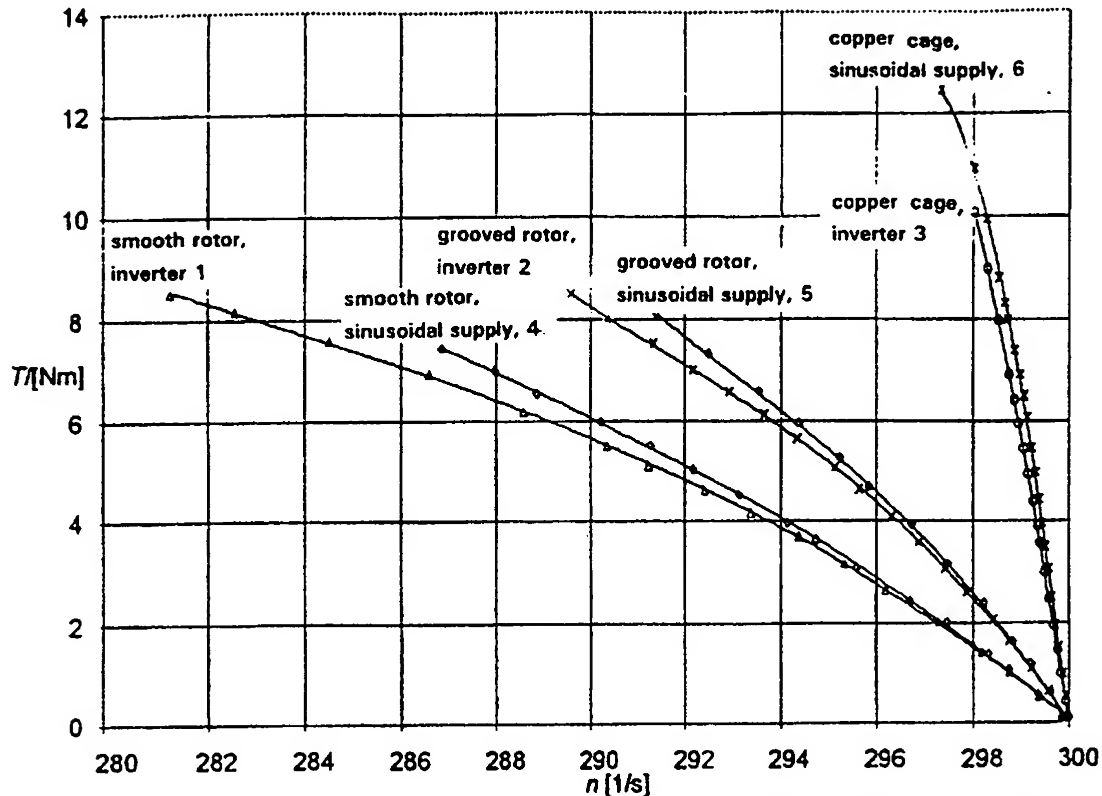
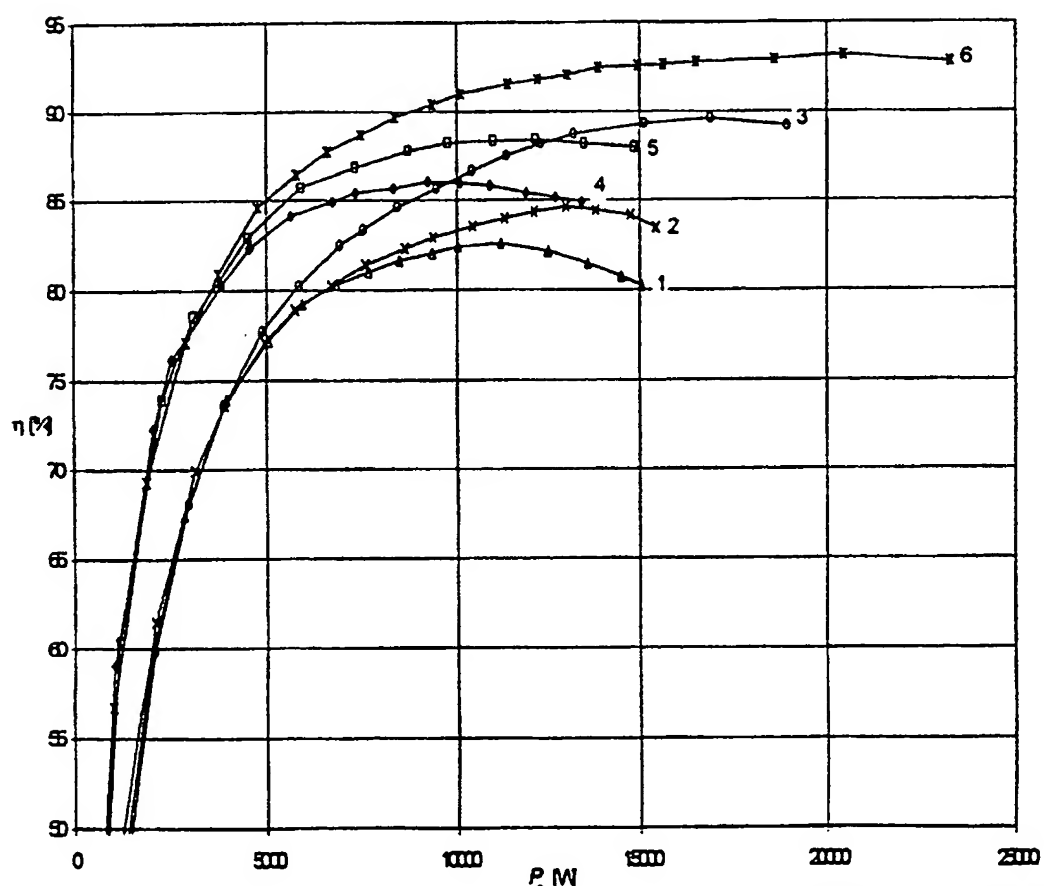

14
12
10
8
6
4
2
0
T/[Nm]
280
282
284
286
288
290
292
294
296
298
300
n [1/s]
smooth rotor,
inverter 1
grooved rotor,
inverter 2
smooth rotor,
sinusoidal supply, 4
grooved rotor,
sinusoidal supply, 5
copper cage,
sinusoidal supply, 6
copper cage,
inverter 3

FIG 5c


95
90
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2000
2500
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2
1

FIG 5d

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 97/00338

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H02K 17/16
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 3131772 A1 (SIEMENS AG), 24 February 1983 (24.02.83), figure 4, abstract --	1-14
X	DE 3127965 A1 (SIEMENS AG), 27 January 1983 (27.01.83), figure 3, abstract --	1-14
A	DE 3306548 A1 (SIEMENS AG), 23 August 1984 (23.08.84), abstract --	1-14
A	US 5260620 A (G.W. MORRILL), 9 November 1993 (09.11.93), figures 2,3,11, abstract --	2,3

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 Sept 1997	08 -10- 1997

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 97/00338

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 2014373 A (HITACHI, LTD.), 22 August 1979 (22.08.79), figure 3, abstract --	2,3,11
A	DE 391971 C (ALLGEMEINE ELEKTRICITÄTS-GESELLSCHAFT), 14 March 1924 (14.03.24) -- --------	5,7,12

INTERNATIONAL SEARCH REPORT
Information on patent family members

01/09/97

International application No.
PCT/FI 97/00338

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 3131772 A1	24/02/83	NONE	
DE 3127965 A1	27/01/83	NONE	
DE 3306548 A1	23/08/84	JP 59162753 A	13/09/84
US 5260620 A	09/11/93	AU 655517 B	22/12/94
		AU 2961292 A	16/09/93
		CA 2083974 A	10/09/93
		DE 69303956 D,T	06/03/97
		EP 0564759 A,B	13/10/93
GB 2014373 A	22/08/79	DE 2904638 A	09/08/79
		JP 54105712 A	20/08/79
DE 391971 C	14/03/24	NONE	